ULV Intel® Celeron® M Processor at 600 MHz for Embedded Applications

Thermal Design Guide

May 2004

Order Number: 302288-001

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Revision History

Date	Revision	Description
May 2004	302288-001	Initial public release of this document.

1.0 Introduction

This document provides thermal design guidelines for the Ultra Low Voltage Intel® Celeron® M Processor at 600 MHz for Embedded Applications in the Micro-Flip Chip Ball Grid Array (micro-FCBGA) package. Detailed mechanical and thermal specifications for this processor can be found in the *ULV Intel® Celeron® M Processor Datasheet*. This design guide specifically outlines recommendations and reference designs for natural convection (fanless) thermal solutions.

The information provided in this document is for reference only and additional validation must be performed prior to implementing the thermal designs into final production. The intent of this document is to assist OEMs with the development of thermal solutions for their individual designs. The final thermal solution, including the heat sink, attachment method, and thermal interface material (TIM) must comply with the mechanical design, environmental, and reliability requirements delineated in the *ULV Intel® Celeron® M Processor Datasheet*. It is the responsibility of each OEM to validate the thermal solution design with their specific applications.

1.1 Document Goals

This document describes the thermal characteristics of the ULV Intel® Celeron® M Processor at 600 MHz and provides guidelines for meeting the thermal requirements imposed on a uni-processor system. The reference thermal solutions presented in this document are specifically designed for natural convection, applied computing applications in the mini-ITX and vertical compute blade form factors.

1.2 Document Scope

This document discusses the thermal management techniques for the ULV Intel® Celeron® M Processor at 600 MHz, specifically in embedded computing applications. The physical dimensions and power numbers used in this document are for reference only. Please refer to the processor’s datasheet for the product dimensions, thermal design power, and maximum junction temperature. In case of conflict the data in the datasheet supersedes any data in this document.

1.3 Related Documents

Table 1. Document References

Title	Number
ULV Intel® Celeron® M Processor Datasheet, Rev. 1.0	301753
Intel® Pentium® M Processor and Intel® Celeron® M Processor for Embedded Applications Thermal Design Guide, Rev 2.0	273885

1.4 Definition of Terms

Table 2. Definitions of Terms

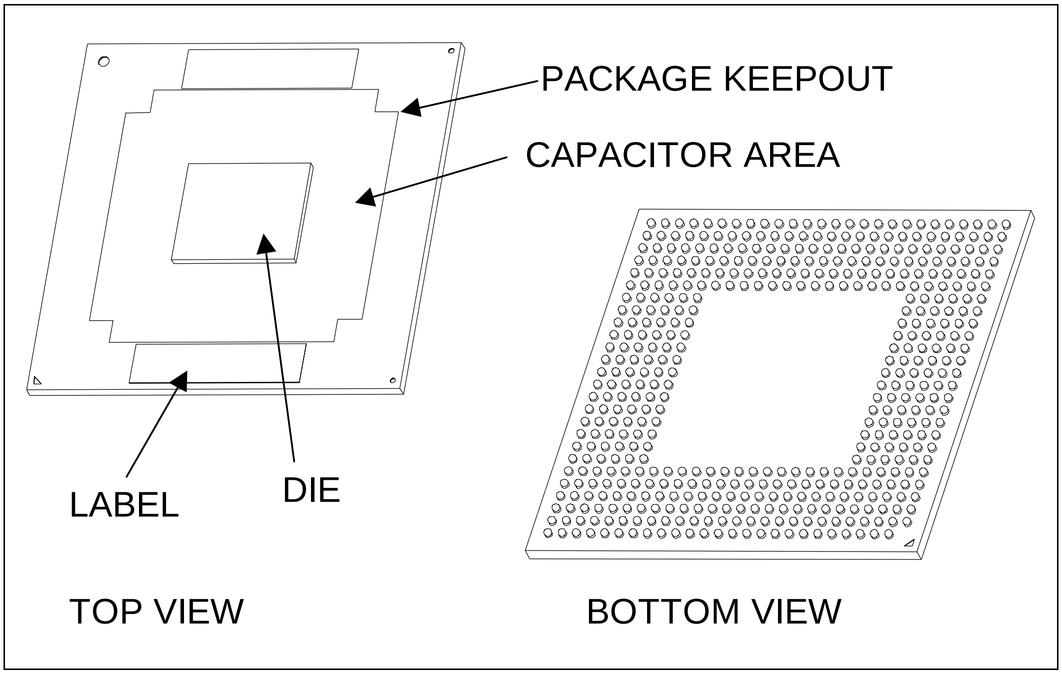
Term	Definition
CFM	Cubic Feet per Minute
LFM	Linear Feet per Minute
Natural Convection Cooling (free convection)	The transferring of heat from a surface to a fluid, i.e., air or liquid, where the convection is generated by natural fluid buoyancy. No airflow devices (i.e., fans) are used in the system.
PCB	Printed Circuit Board
Ψ_{JA}	The thermal resistance between the processor's junction and the ambient air. This is defined and controlled by the system thermal solution.
Ψ_{JS}	The junction to sink thermal resistance, which is dependent on the thermal interface material. Also referred to as Ψ_{TIM}.
$T_{junction}$	The measured junction temperature of the processor.
$T_{junction\text{-}max}$	The maximum junction temperature of the processor, as specified in the processor datasheet.
T_{LA} ($T_{Local\text{-}Ambient}$)	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured approximately one inch (25.4 mm) upstream of a passive heatsink or at the fan inlet of an active heatsink.
Ψ_{SA}	The sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as ($T_S – T_A$) / Total Package Power.
Thermal Design Power (TDP)	A design point for the processor. OEMs must design thermal solutions that meet TDP and $T_{junction}$ specifications as specified in the processor's datasheet.
Thermal Interface Material (TIM)	The thermally conductive compound between the heatsink and processor die. This material fills air gaps and voids, and improves the spread of heat from the die to the heatsink.

2.0 Mechanical Guidelines

2.1 Processor Package

The ULV Intel® Celeron® M Processor at 600 MHz with 400-MHz Front side bus is available in the 478-ball Micro-Flip Chip Ball Grid package technology. Detailed mechanical information including package dimensions can be found in the processor datasheet. Figure 1 shows a basic representation of the Micro-FCBGA package.

Figure 1. Top and Bottom Isometric Views of the Micro-FCBGA Package



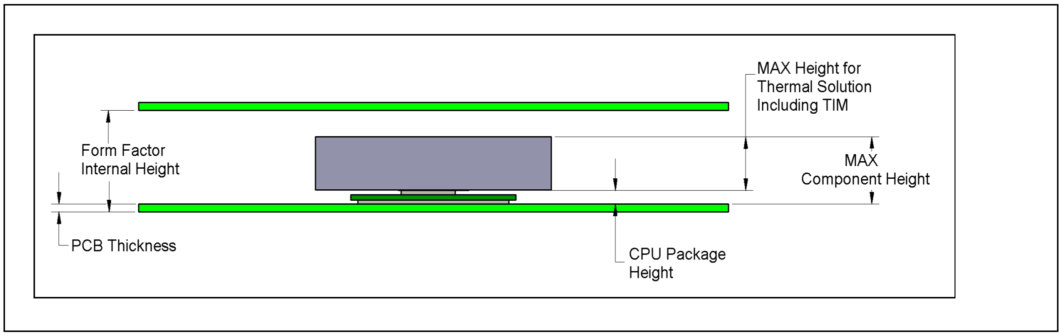
2.2 Thermal Solution Volumetric Constraint Zones

The reference thermal solutions enabled for the ULV Intel® Celeron® M Processor at 600 MHz for Embedded Applications have volumetric constraint zones that will allow for the thermal solution to be assembled to a system board. System designers must take these zones into account so that the thermal solution will be properly assembled to the board and not interfere with any other components. The volumetric constraint zones for the reference natural convection thermal solutions are shown in Appendix A, "Mechanical Drawings." These zones are specific to the natural convection solutions in the mini-ITX and a vertical compute blade form factors. Additional volumetric constraints for forced convection thermal solutions are delineated in the *Intel® Pentium® M Processor and Intel® Celeron® M Processor for Embedded Applications Thermal Design Guide*.

The maximum allowable height for a thermal solution is very important in the overall thermal performance and is a factor in the volumetric constraint for a thermal solution. This height is determined by the form factor in which the computer system is placed. For the Intel reference thermal solutions, the maximum allowable height was based on the mini-ITX and a vertical blade form factor requirements. These solutions may apply for other form factors, but it is up to the

system integrator to ensure that all thermal and mechanical requirements are validated in the final intended configuration. Figure 2 shows a generic mechanical stack-up for the ULV Intel® Celeron® M Processor at 600 MHz in an embedded form factor. Figure 2 shows the mechanical stack-up of the processor and the parameters that need to be accounted for when determining the maximum allowable height for a thermal solution.

Figure 2. Typical Mechanical Stackup



3.0 Thermal Design Guidelines

The performance of the thermal solution depends on many parameters, including the processor's:

- Thermal Design Power (TDP)
- Maximum junction temperature ($T_{junction-max}$)
- Operating ambient temperature
- Airflow

The guidelines and recommendations presented in this document are based on specific parameters and component placement within the system. This document specifically provides recommendations for designing a natural convection thermal solution.

To develop a reliable thermal solution all of the appropriate variables must be considered. Thermal simulations and characterizations must be performed. The solutions presented in this document must be validated in their final intended system.

3.1 Heatsink Design Considerations

To remove the heat from the processor, three basic parameters should be considered:

1. The area of the surface on which the heat transfer takes place. Without any enhancements, this is the surface of the processor die. One method used to improve thermal performance is by attaching a heatsink to the die. A heatsink can increase the effective heat transfer surface area by conducting heat out of the die and into the surrounding air through fins attached to the heatsink base.
2. The conduction path from the heat source to the heatsink fins. Providing a direct conduction path from the heat source to the heatsink fins and selecting materials with higher thermal conductivity typically improves heatsink performance. The length, thickness, and conductivity of the conduction path from the heat source to the fins directly impact the thermal performance of the heatsink. In particular, the quality of the contact between the package die and the heatsink base has a higher impact on the overall thermal solution performance as processor cooling requirements become stricter. Thermal Interface Material (TIM) is used to fill in the gap between the die and the bottom surface of the heatsink, and thereby improve the overall performance of the stack-up (die-TIM-Heatsink). With extremely poor heatsink interface flatness or roughness, TIM may not adequately fill the gap. The TIM thermal performance depends on its thermal conductivity as well as the pressure applied to it.
3. The heat transfer conditions on the surface on which heat transfer takes place. Convective heat transfer occurs between the airflow and the surface exposed to the flow. It is characterized by the local ambient temperature of the air, T_{LA}, and the local air velocity over the surface. The higher the air velocity over the surface, and the cooler the air, the more efficient is the resulting cooling. The nature of the airflow can also enhance heat transfer via convection. Turbulent flow can provide improvement over laminar flow. In the case of a heatsink, the surface exposed to the flow includes in particular the fin faces and the heatsink base.

3.1.1 Heatsink Size

The size of the heatsink is dictated by height restrictions in a system and by the real estate available on the motherboard. The height of the heatsink must comply with the requirements and recommendations published for the motherboard form factor of interest.

3.1.2 Heatsink Weight

With the need for pushing air cooling to better performance, heatsink solutions tend to grow larger (increase in fin surface) resulting in increased weight. The insertion of highly thermally conductive materials like copper to increase heatsink thermal conduction performance results in even heavier solutions. The heatsink weight must take into consideration the package and socket load limits, the heatsink attach mechanical capabilities, and the mechanical shock and vibration profile targets.

3.1.3 Thermal Interface Material

A thermal interface material between the processor die and the heatsink base is generally required to improve thermal conduction from the die to the heatsink. Many thermal interface materials can be preapplied to the heatsink base prior to shipment from the heatsink supplier and allow direct heatsink attach, without the need for a separate thermal interface material dispense or attach process during final assembly.

All thermal interface materials should be sized and positioned on the heatsink base in a way that ensures the entire processor die area is covered. It is important to compensate for heatsink-to-processor attach positional alignment when selecting the proper thermal interface material size.

When preapplied material is used, it is recommended to have a protective cover over it. This cover must be removed prior to heatsink installation.

3.2 Natural Convection Cooling Considerations

Many factors play an important role in the ability to design a natural convection thermal solution that will keep the processor within its maximum operating temperature. Both processor attributes (i.e., $T_{junction\text{-}max}$, TDP, etc.) and the system attributes need to be considered. These include:

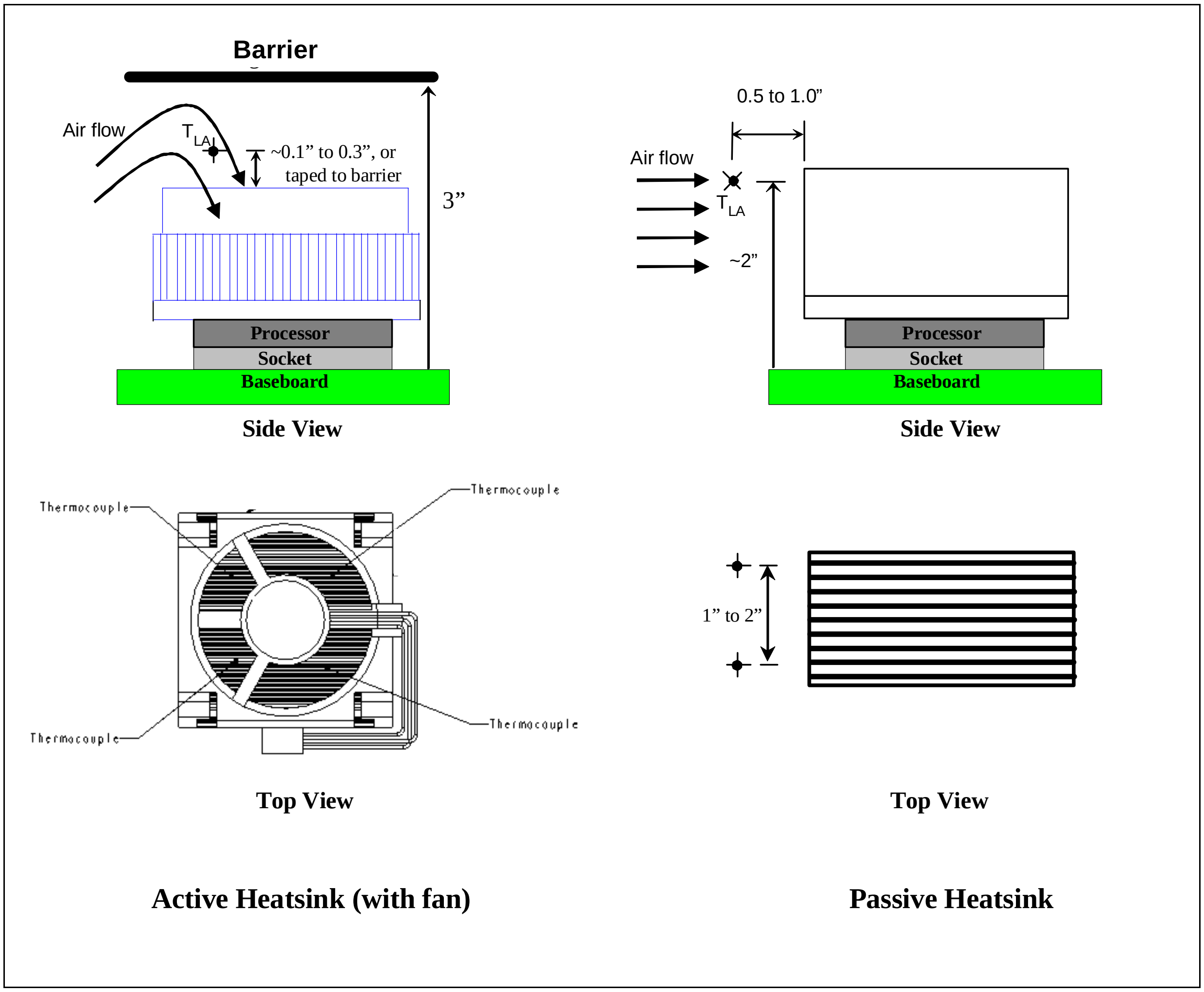
- Operating ambient temperature (T_{LA})
- Heat-generating component placement and system orientation
- Location and size of venting
- Available volume for thermal solution

It is very challenging to design one thermal solution that will apply for multiple form factors. Thermal modeling and analysis needs to be performed in order to optimize the thermal solution for the intended form factor and environment. This in essence makes most natural convection thermal solutions custom designs.

3.2.1 Local Ambient Temperature (T_{LA})

The local ambient temperature (T_{LA}) is a significant influence when developing a thermal solution. The T_{LA} is defined as the local temperature measured approximately one inch upstream of the thermal solution in a passive system or directly above the fan of an active solution. For a natural convection system the T_{LA} is measured at the same points as a passive system but it depends on the system orientation. This location should be chosen so that the measured temperature is not affected by the air that is convecting away from the heatsink. In the vertical orientation, the measurement should be taken at the leading edge (closest to the ground). In a horizontal configuration, the measurement should be taken at the sides of the heatsink. The local ambient temperature includes the ambient temperature plus any temperature rise due to other components in the system ($T_{LA} = T_A + T_{RISE}$). The measurement location of T_{LA} is shown in Figure 3.

Figure 3. Local Ambient Temperature Location



3.2.2 Thermal Resistance of a Heatsink

The thermal characterization parameter or Ψ (Psi) is calculated for a given thermal solution so that it may be compared to other thermal solutions in identical conditions. In any computer system it is necessary to calculate the required thermal characterization parameter needed in order to keep the processor within its operating temperatures. The thermal solution must maintain the processor die at or below the specified junction temperature. The equation for calculating the junction-to-ambient thermal characterization parameter is shown in Equation 1.

Equation 1. Junction-to-Ambient Thermal Characterization Parameter

$$\psi_{JA} = \frac{T_{J\max} - T_{LA}}{TDP}$$

Where:

Ψ_{JA} = Junction-to-ambient thermal resistance in °C/W

T_{Jmax} = Maximum junction temperature of processor as specified by the datasheet in °C

T_{LA} = Maximum local ambient temperature in °C

TDP = Thermal Design Power in W

When calculating the required Ψ, the T_{LA} is important to determine the allowable temperature rise from the maximum operating environment to the component's maximum specification. It is important to know that lower Ψ_{JA} values require better thermal solutions and vice versa.

Typical T_{LA} values for natural convection systems range from 35-55 °C. As an example, the thermal solution needed to cool an Intel® Processor with a T_{Jmax} of 100 °C and a TDP of 7.0 W in a system with a T_{LA} = 50 °C, would need to have a junction-to-ambient thermal resistance of:

$$\psi_{JA} = \frac{100^{\circ}C - 50^{\circ}C}{7W} = 7.14^{\circ}C/W$$

The thermal solution for this situation requires a thermal solution with a thermal characterization parameter less than or equal to 7.14 °C/W to keep the component temperature specifications below.

Figure 4 shows the relative difficulty and limitations to design a natural convection solution for the ULV Intel® Celeron® M Processor at 600 MHz.

Figure 4. ULV Intel® Celeron® M Processor at 600 MHz Natural Convection Ψ_{JA} Feasibility

ULV Intel® Celeron® M Processor			Required Thermal Solution Performance at Various Ambient Temperatures					
			40°C	45°C	50°C	55°C	60°C	70°C
Frequency MHz	TDP Max (W)	Tj Max (°C)	Ψ ja (°C/W)	Ψ ja (°C/W)	Ψ ja (°C/W)	Ψ ja (°C/W)	Ψ ja (°C/W)	Ψ ja (°C/W)
600	7.0	100	8.57	7.86	7.14	6.43	5.71	4.29

FEASIBLE CHALLENGING

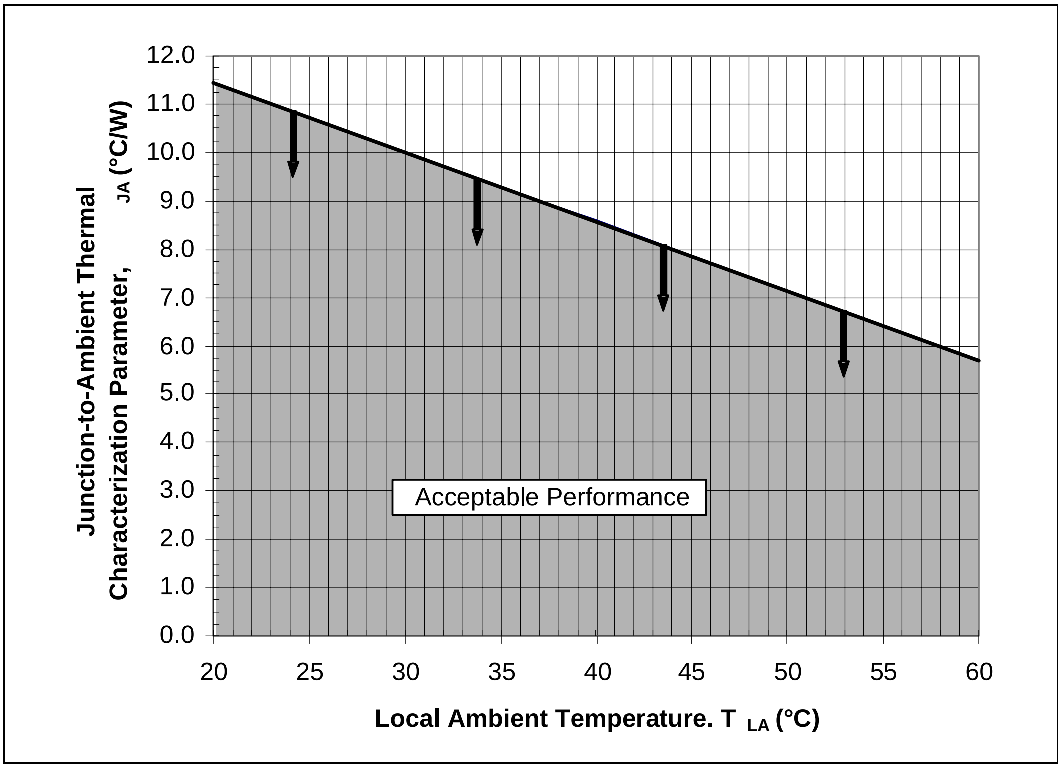
Note: Specifications (TDP, Tj) provided for reference only. Refer to the latest datasheet for the most recent data.

$\Psi_{JA} = (T_{junction} - T_{ambient})$/ TDP, junction-to-ambient thermal resistance for the thermal solution.

Figure 5 shows the thermal solutions requirements for the ULV Intel® Celeron® M Processor at 600 MHz as a function of increaing T_{LA}.

Note: Note that as the T_{LA} increases, a better Thermal Solution is needed (e.g., Ψ_{JA} must decrease).

Figure 5. Required Thermal Solution as Various Ambient Temperature Increases



3.2.3 Component Placement, System Orientation and Venting

The placement of heat generating components in a system has an influence in the ability to develop a natural convection thermal solution. The component placement should be optimized for a number of reasons, these include:

- Minimize the effects of radiated heat: the proximity of the power generating components to each other will affect the local ambient temperature. High power dissipating parts should be placed as far from each other as motherboard size and electrical routing constraints allow.
- Location of venting in the chassis: the vents in the chassis will allow for the heat to escape the system and for external air that is at a lower temperature to enter the chassis. For critical components with the highest amount of power generation (usually the CPU), it is necessary to place them close to the vents in the chassis. This will facilitate the movement of air caused by thermodynamic effects.
- Orientation of the system: the orientation of the system influences where the components should be placed and the ability to develop a natural convection solution. If the system is in a vertical configuration, the processor should be placed at the bottom of the motherboard. This will allow for the air to rise and prevent any unnecessary pre-heating of the air surrounding the processor. When the system is in a horizontal configuration, the processor should be place on the topside of the motherboard in order to avoid trapping the air underneath the board. The main goal of the component placement in regards to system orientation is to minimize the local ambient temperature and avoid placing the processor and other critical components in unfavorable boundary conditions.

The component placement, location of the vents, and the orientation of the motherboard influence the ability to develop and optimized natural convection thermal solution. It is highly recommended that thermal simulations and analysis are performed on a system level. The reference designs in Section 3.3 were optimized with a Computational Fluid Dynamics (CFD) program. With CFD analysis, multiple tradeoff scenarios and system configurations can be modeled to optimize the thermal solution to meet component's thermal requirements.

Proper system level thermal modeling allows the thermal solution designer to optimize thermal solutions and be confident in their performance, prior to fabricating hardware. This results in better solutions, lower design time, and faster integration.

3.2.4 ULV Intel® Celeron® M Processor at 600 MHz Thermal Specifications

Thermal data for the ULV Intel® Celeron® M Processor at 600 MHz is presented in Table 1. The data is provided for informational purposes only. Please refer to the processor datasheet for the most up to date information. In the event of conflict, the processor's datasheet supersedes information provided in this document.

Table 3. Processor Thermal Specifications

Processor	Frequency (MHz)	Thermal Design Power (W)	Minimum Junction Temperature (°C)	Maximum Junction Temperature (°C)
ULV Intel® Celeron® M Processor at 600 MHz	600	7.0	0	100

3.3 Processor Power

The processor's power is specified as Thermal Design Power (TDP) for thermal solution design. TDP is defined as the worst-case power dissipated by the processor while executing publicly available software under normal operation conditions, at nominal voltages that meet the load line specifications. The TDP definition is synonymous with the Thermal Design Power (typical) specification referred to in previous Intel data sheets. The Intel TDP specification is a recommended design point and is not representative of the absolute maximum power the processor may dissipate under worst case conditions. For any excursions beyond TDP, the Thermal Monitor feature is available to maintain the processor thermal specifications. Refer to the processor datasheet for details regarding the Thermal Design Power specifications and Section 3.5 for the Intel Thermal Monitor.

3.4 Thermal Diode

The ULV Intel® Celeron® M Processor at 600 MHz incorporates two methods of monitoring die temperature, the Thermal Monitor and the thermal diode. The Intel Thermal Monitor must be used to determine when the maximum specified processor junction temperature has been reached. The second method, the thermal diode, can be read by an off-die analog/digital converter (a thermal sensor) located on the motherboard, or a stand-alone measurement kit. The thermal diode may be used to monitor the die temperature of the processor for thermal management or instrumentation purposes but cannot be used to indicate that the maximum $T_{junction}$ of the processor has been reached. The thermal diode can only be used for long term, steady state measurement of die temperature. It is not suitable of real time thermal management. For more information refer to the *ULV Intel® Celeron® M Processor Datasheet*.

Note: The reading of the external thermal sensor (on the motherboard) connected to the processor thermal diode signals will not necessarily reflect the temperature of the hottest location on the die. Inaccuracies can include:

- The external thermal sensor
- On-die temperature gradients between the location of the thermal diode and the hottest location on the die
- Time based variations in the die temperature measurement

Time based variations may occur when the sampling rate of the thermal diode (by the thermal sensor) is slower than the rate ate which the T_J temperature may change.

3.5 Thermal Monitor

The Intel Thermal Monitor helps control the processor temperature by activating the Thermal Control Circuit (TCC) when the processor silicon reaches its maximum operating temperature. The temperature at which the Intel Thermal Monitor activates the TCC is not user configurable and is not software visible. Bus traffic is snooped in the normal manner, and interrupt requests are latched (and serviced during the time that the clocks are on) while the TCC is active.

With a properly designed and characterized thermal solution, it is anticipated that the TCC would only be activated for very short periods of time when running the most power intensive applications. The processor performance impact due to these brief periods of TCC activation is expected to be so minor that it would not be detectable. An under-designed thermal solution that is not able to prevent excessive activation of the TCC in the anticipated ambient environment may

cause a noticeable performance loss, and may affect the long-term reliability of the processor. In addition, a thermal solution that is significantly under designed may not be capable of cooling the processor even when the TCC is active continuously.

The Intel Thermal Monitor controls the processor temperature by modulating (starting and stopping) the processor core clocks when the processor silicon reaches its maximum operating temperature. The Intel Thermal Monitor uses two modes to activate the TCC: Automatic mode and On-Demand mode. If both modes are activated, automatic mode takes precedence. The Intel Thermal Monitor Automatic Mode must be enabled via BIOS for the processor to be operating within specifications. This mode is selected by writing values to the Model Specific Registers (MSRs) of the processor. After the automatic mode is enabled, the TCC will activate only when the internal die temperature reaches the maximum allowed value for operation.

When Intel Thermal Monitor is enabled, and a high temperature situation exists, the clocks will be modulated by alternately turning the clocks off and on at a 50% duty cycle. Cycle times are processor speed dependent and will decrease linearly as processor core frequencies increase. After the temperature has returned to a non-critical level, modulation ceases and the TCC goes inactive. A small amount of hysteresis has been included to prevent rapid active/inactive transitions of the TCC when the processor temperature is near the trip point. The duty cycle is factory configured and cannot be modified. Also, the automatic mode does not require any additional hardware, software drivers or interrupt handling routines. Processor performance will be decreased by the same amount as the duty cycle when the TCC is active, however, with a properly designed and characterized thermal solution the TCC most likely will never be activated, or will be activated only briefly during the most power intensive applications.

The TCC may also be activated using On-Demand mode. If bit 4 of the ACPI Intel Thermal Monitor Control register is written to a logic one, the TCC will be activated immediately, independent of the processor temperature. When using On-Demand mode to activate the TCC, the duty cycle of the clock modulation is programmable via bits 3:1 of the same ACPI Intel Thermal Monitor Control Register. In automatic mode, the duty cycle is fixed at 50% on, 50% off, in On-Demand mode, the duty cycle can be programmed from 12.5% on/ 87.5% off, to 87.5% on/12.5% off in 12.5% increments. On-Demand mode can be used at the same time automatic mode is enabled, however, if the system tries to enable the TCC via On-Demand mode at the same time automatic mode is enabled and a high temperature condition exists, automatic mode will take precedence.

An external signal, PROCHOT# (processor hot) is asserted when the processor detects that its temperature is above the thermal trip point. Bus snooping and interrupt latching are also active while the TCC is active.

Note: PROCHOT# will not be asserted when the processor is in the Stop-Grant, Sleep, and Deep Sleep low power states (internal clocks stopped), hence the thermal diode reading must be used as a safeguard to maintain the processor junction temperature within the 100 °C (maximum) specification. If the platform thermal solution is not able to maintain the processor junction temperature within the maximum specification, the system must initiate an orderly shutdown to prevent damage. If the processor enters one of the above low power states with PROCHOT# already asserted, PROCHOT# will remain asserted until the processor exits the low power state and the processor junction temperature drops below the thermal trip point.

If automatic mode is disabled the processor will be operating out of specification. Whether the automatic or On-Demand modes are enabled or not, in the event of a catastrophic cooling failure, the processor will automatically shut down when the silicon has reached a temperature of approximately 125 °C. At this point the FSB signal THERMTRIP# will go active. THERMTRIP#

activation is independent of processor activity and does not generate any bus cycles. When THERMTRIP# is asserted, the processor core voltage must be shut down within the time specified in the processor datasheet.

3.6 Power Density and Non-uniform Heating

The ULV Intel® Celeron® M Processor at 600 MHz die does not exhibit an even power distribution over its surface area. Non-uniform power distributions may adversely affect the overall thermal solution performance. The Thermal Interface Material (TIM), which functions as the first layer of heat spreading above the die, will be most susceptible to non-uniform die power characteristics.

The processor density factor for the ULV Intel® Celeron® M Processor at 600 MHz will be higher than on previous processors. Processor thermal solution designers must account for the increase in expected thermal impedance (or resistance) form the thermal interface material when it is attached to the processor die. Processor heatsink performance will not be affected to the same degree as the TIM and is dependent on many factors, including heatsink size, base thickness, and material used. It is the responsibility of the OEM thermal solution designer to validate overall thermal solution performance in the intended system.

3.7 Processor Thermal Solutions

The natural convection reference thermal solutions enabled for the ULV Intel® Celeron® M Processor at 600 MHz were designed for the mini-ITX form factor and a typical vertical compute blade form factor. These solutions were designed with a Computational Fluid Dynamics program. As stated in Section 3.2 it is very important to consider all system and component boundary conditions when designing a natural convection thermal solution. The guidelines and recommendations presented in this document are based on specific parameters. It is the responsibility of each product design team to verify that thermal solutions are suitable for their specific use.

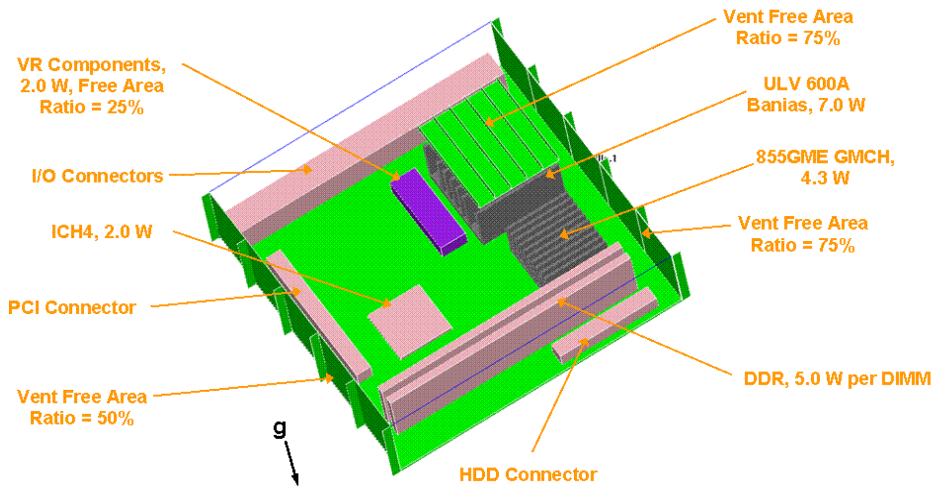
The performance of the thermal solution is dependant on many parameters including the processor's Thermal Design Power (TDP), maximum junction temperature ($T_{junction\text{-}max}$), the operating ambient temperature, and system airflow. In this document the designs are targeted for a natural convection environment, so there is no airflow. When performing thermal solution verification testing it is required that a Thermal Test Vehicle (TTV) be used. For more information on the TTV contact your Intel field sales representative.

3.7.1 Mini-ITX Form Factor Reference Solution

This solution was prototyped and the performance was verified with a Intel® Celeron® M Thermal Test Vehicle. This thermal verification testing is not adequate for statistical purposes. The intent of the testing was only to verify that the thermal components were performing within reasonable expectations, based on computer modeling and component specifications.

As stated in the previous sections, it is very important to consider the system boundary conditions and other components when designing a natural convection thermal solution. Figure 6 shows the system configuration for the CFD thermal simulations.

Figure 6. Mini-ITX Thermal Model



The thermal model takes into consideration the major heat dissipating components, such as the CPU, MCH, ICH, Memory and Voltage regulator components. The component placement on the motherboard is limited by the electrical routing constraints and the motherboard size. A mini-ITX motherboard measures approximately 170 mm x 170 mm. The location of the venting inside the chassis is positioned to provide the best ventilation for the critical components. The Free Area Ratio (FAR) of the vents is important because this determines how much air can enter or leave the chassis. This design for the mini-ITX form factor was done with the board in a horizontal position. The thermal performance of the heatsink can be expected to change if the board is oriented vertically. Through the use of CFD software the heatsink and chassis parameters can be optimized to obtain the best performing thermal solution.

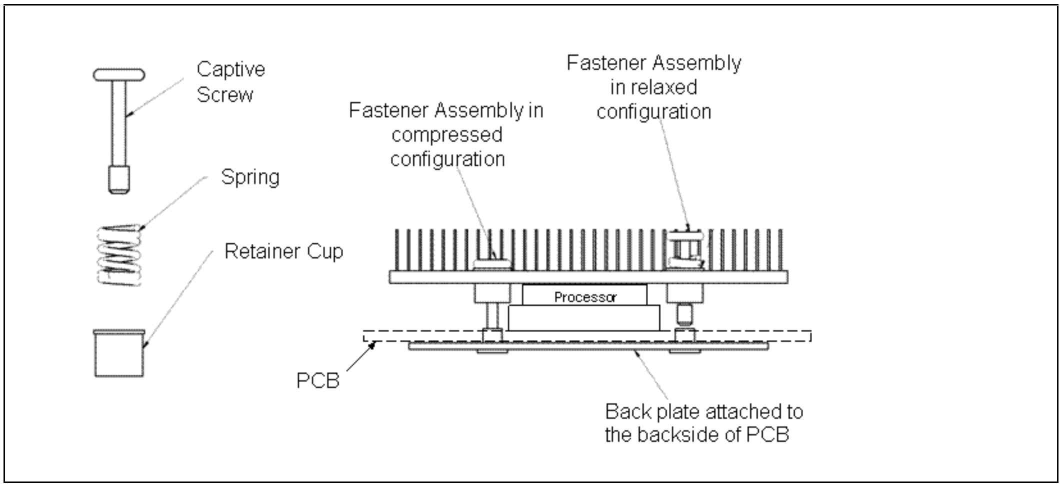
The heatsink for the mini-ITX form factor, shown in Appendix A, “Mechanical Drawings,” was designed to meet the required thermal performance for a maximum local ambient temperature of 45° C. The performance of this heatsink in lab verification testing demonstrated a junction-to-ambient thermal resistance of 5.57° C/W. Note that the thermal modeling predicted a junction-to-ambient thermal resistance of 6.24° C/W. The difference can be attributed to the fact that the thermal model did not account for heat transfer via radiation. Modeling radiation in any CFD program is challenging, due to the variability of radiation view factors and the emmisivity of materials. Neglecting radiation in thermal models will result in more conservative results. It is recommended to perform verification tests to further fine tune the thermal solution performance calculations.

The lab verification testing only simulated the power dissipation of the processor. In a real system all components would have power dissipation. The thermal model resulting junction-to-ambient thermal resistance of 6.24° C/W also simulates the scenario with the processor as the only heat dissipating component. The junction-to-ambient thermal resistance with all components dissipating power, as shown in Figure 6 is 7.62° C/W, in the thermal model. One can expect a similar trend for the difference in thermal resistance between the thermal model and a real test with all components

dissipating heat. To use this processor in these conditions, it is recommended for this design to target 7.62° C/W to meet the thermal resistance target. This resulting thermal resistance will meet the thermal targets for the ULV Intel® Celeron® M Processor at 600 MHz at a TLA of 45° C.

The thermal solution is attached to the motherboard using a backplate that is fastened to the motherboard by four screws. This attach method uses spring-loaded fasteners to apply an even load on the processor die. The backplate, when assembled, will be flush against the backside of the motherboards. Refer to Figure 7 for an example.

Figure 7. Sample Attachment Method

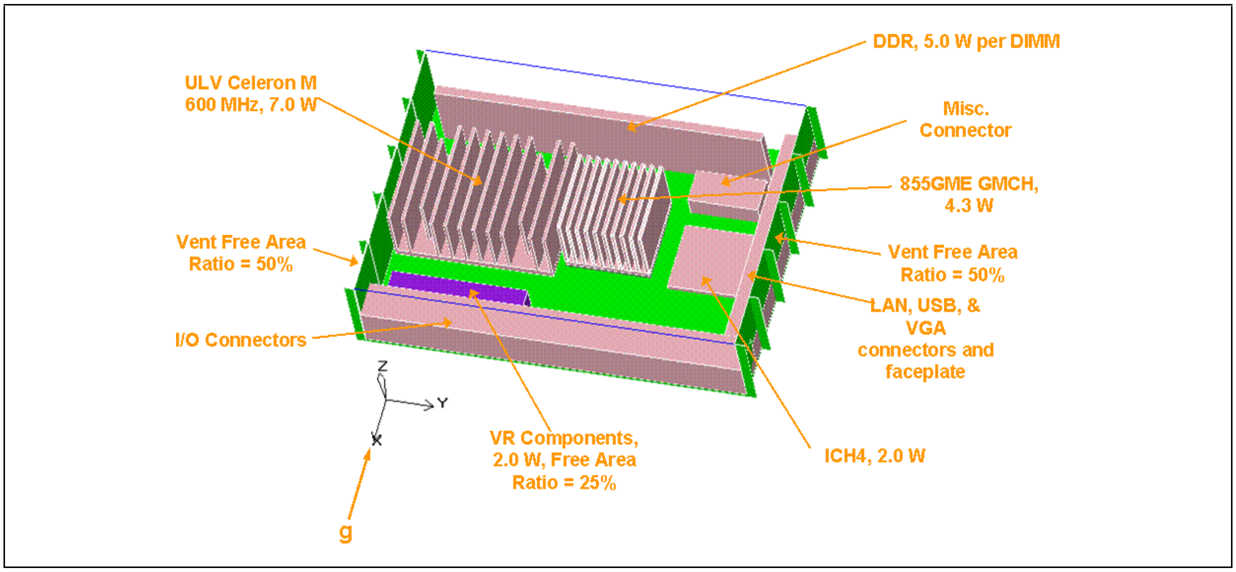


3.7.2 Vertical Compute Blade Thermal Solution

The Intel reference solution for a typical vertical compute blade was optimized using computer modeling. In addition this solution was prototyped and the performance was verified with a Intel® Celeron® M Thermal Test Vehicle. The intent of the testing was to verify that the thermal components were performing within reasonable expectations, based on computer modeling and component specifications.

Figure 8 shows the system configuration for the CFD thermal simulations.

Figure 8. Vertical Compute Blade Thermal Model



Designing a single natural convection solution for all vertical computing blades is very difficult because there are numerous form factors in the industry. For this design, the motherboard design was based on the dimensions of a PICMG* 1.0 single board computer. This solution may be applicable for other similar form factors, but the thermal solution needs to be modeled, prototyped and validated.

This thermal model takes into consideration the major heat dissipating components, such as the CPU, MCH, ICH, Memory and Voltage regulator components. The dimensions of this board are 122 mm x 169 mm and the board is oriented in a vertical configuration with gravity in the negative x-direction as shown in Figure 8. The performance of this thermal solution is greatly affected by the direction of gravity. The heatsink fins should be oriented so that they are parallel to the direction of gravity. This will allow for maximum convection from the fin surface and facilitate heat transfer. Just as with any natural convection design, the locations of the vents play a critical role in the ability to design and effective solution. In this design, the configuration shown is much more difficult to cool than if the gravity is in the negative y-direction. This is due to the fact that the vents are located on the surfaces in the y-direction of the enclosure. With this configuration the heat convecting from the heatsink fins can directly escape the chassis. Alternatively, the heat convecting from the fins, as shown in Figure 8, has to travel in a horizontal direction to escape the chassis and this can create a higher local ambient temperature.

The heatsink for the vertical blade form factor, shown in Appendix A, “Mechanical Drawings,” was designed to meet the required thermal performance for a maximum local ambient temperature of 45° C. The performance of this heatsink in lab verification testing demonstrated a junction-to-ambient thermal resistance of 5.29° C/W. Note that the thermal modeling predicted a junction-to-

ambient thermal resistance of 6.80 C/W. The difference can be attributed to the fact that the thermal model did not account for heat transfer via radiation. Modeling radiation in any CFD program is challenging, due to the variability of radiation view factors and the emmisivity of materials. Neglecting radiation in thermal models will result in more conservative results. It is recommended to perform verification tests to further fine tune the thermal solution performance calculations.

The lab verification testing only simulated the power dissipation of the processor. In a real system all components would have power dissipation. The thermal model resulting junction-to-ambient thermal resistance of 6.80° C/W also simulates the scenario with the processor as the only heat dissipating component. The junction-to-ambient thermal resistance with all components dissipating power, as shown in Figure 8 is 7.80° C/W, in the thermal model. One can expect a similar trend for the difference in thermal resistance between the thermal model and a real test with all components dissipating heat. To use this processor in these conditions, it is recommended to meet 7.80° C/W as the thermal resistance target. This resulting thermal resistance will meet the thermal targets for the ULV Intel® Celeron® M Processor at 600 MHz at a TLA of 45° C.

The thermal solution is attached to the motherboard using a backplate that is fastened to the motherboard by four screws. This attach method uses spring-loaded fasteners to apply an even load on the processor die. The backplate, when assembled, will be flush against the backside of the motherboards. Refer to Figure 7 for an example.

3.7.3 Additional Heatsink Designs

There are multiple alterative heatsink designs that have been enabled for the ULV Intel® Celeron® M Processor at 600 MHz for systems that do not require a natural convection solution. These solutions are passive thermal solutions (with airflow) and active fansinks. For more information on heatsink details and performance curves refer to the *Intel® Pentium® M processor and Intel® Celeron® M processor for Embedded Applications Thermal Design Guide*.

3.7.4 Recommended Thermal Interface Material (TIM)

It is important to understand and consider the impact that the interface between the processor and the heatsink base has on the overall thermal solution. Specifically, the bond line thickness, interface material area, and interface material thermal conductivity must be selected to optimize the thermal solution.

It is important to minimize the thickness of the thermal interface material, commonly referred to as the bond line thickness. A large gap between the heatsink base an processor die yields a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heatsink base and the die, plus the thickness of the TIM, and the clamping force applied by the heatsink attachment method. To ensure proper and consistent thermal performance the TIM and application process must be properly designed.

The heatsink solutions in this document were optimized using a high performance grease Thermal Interface Material (TIM) with low thermal impedance. The heatsinks were designed using ShinEtsu* G751 thermal grease. Vendor information for this material is provided in Section 4.0. Alternative materials may be used at the user's discretion. The entire heatsink assembly, including the heatsink, attach method, and thermal interface material, must be validated together in its final intended use.

4.0 Vendor Contact Information

Table 4. Vendor Contact Information

Supplier	Contact	Phone	Email	Components
Cooler Master Unit 2C 603 FIrst Avenue Raritan, NJ USA 08869	Wendy Lin	(908)252-9400	wendy@coolermaster.com	• Mini-ITX Aluminum Heatsink Reference No. EID-BAN600A-NC-001 • Vertical Blade Copper Heatsink Reference No. EID-BAN600A-NCV-002
Shin-Etsu Micro Si, Inc. 10028 S. 51st St. Phoenix, AZ 85044		(480) 893-8898	http://www.microsi.com	Thermal Interface Material (ShinEtsu PN G751)
Power Devices Inc. 26941 Cabot Rd.,Bldg. 124 Laguna Hills, CA 92653		(949) 582-6712	http:// www.powerdevices.com	Thermal Interface Material (Powerstrate* 51)

Appendix A Mechanical Drawings

Mechanical Drawings are shown on the following pages.

Figure 9. Mini-ITX Volumetric Constraint Zone (Primary Side)

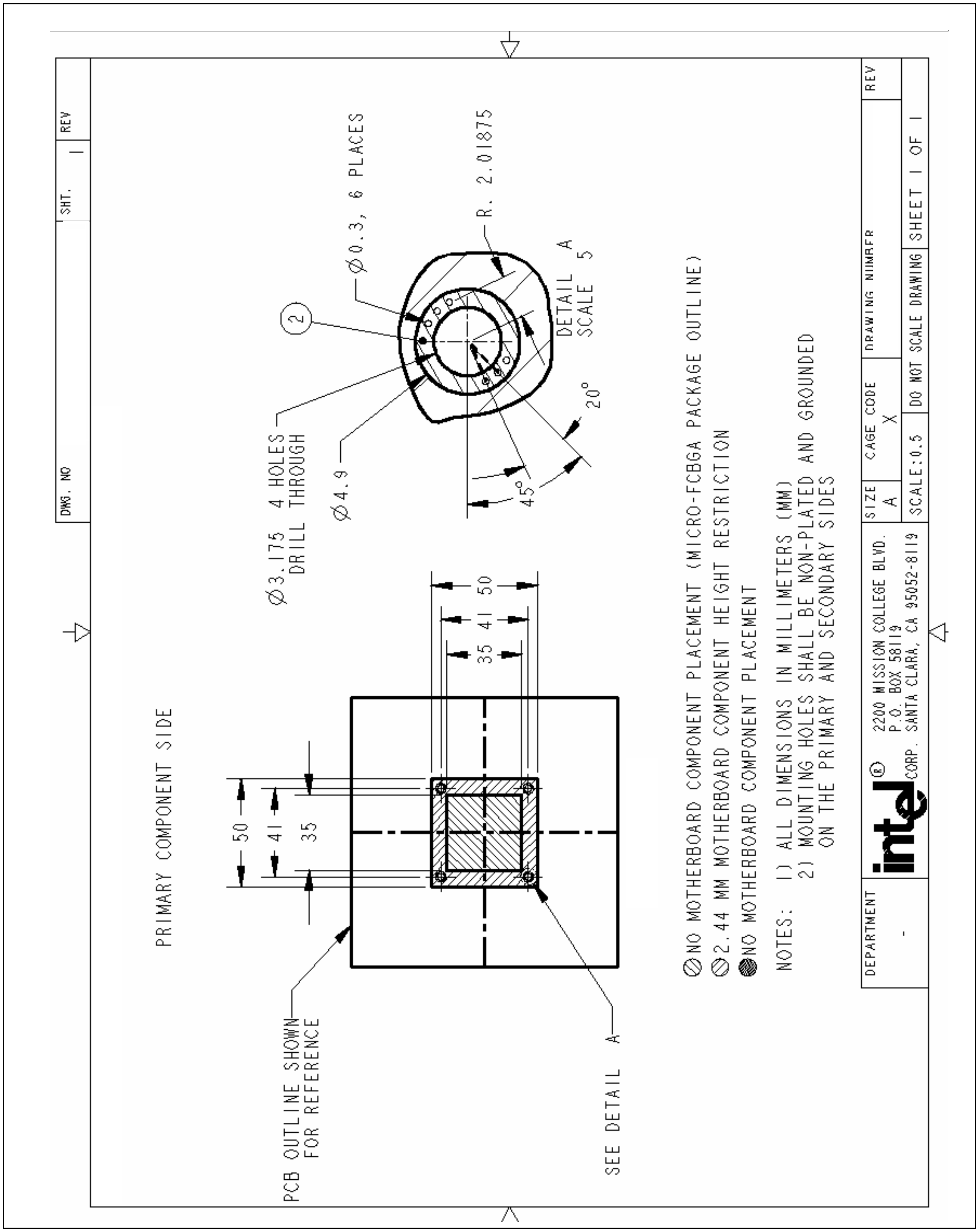


Figure 10. Vertical Compute Blade Volumetric Constraint Zone (Primary Side)

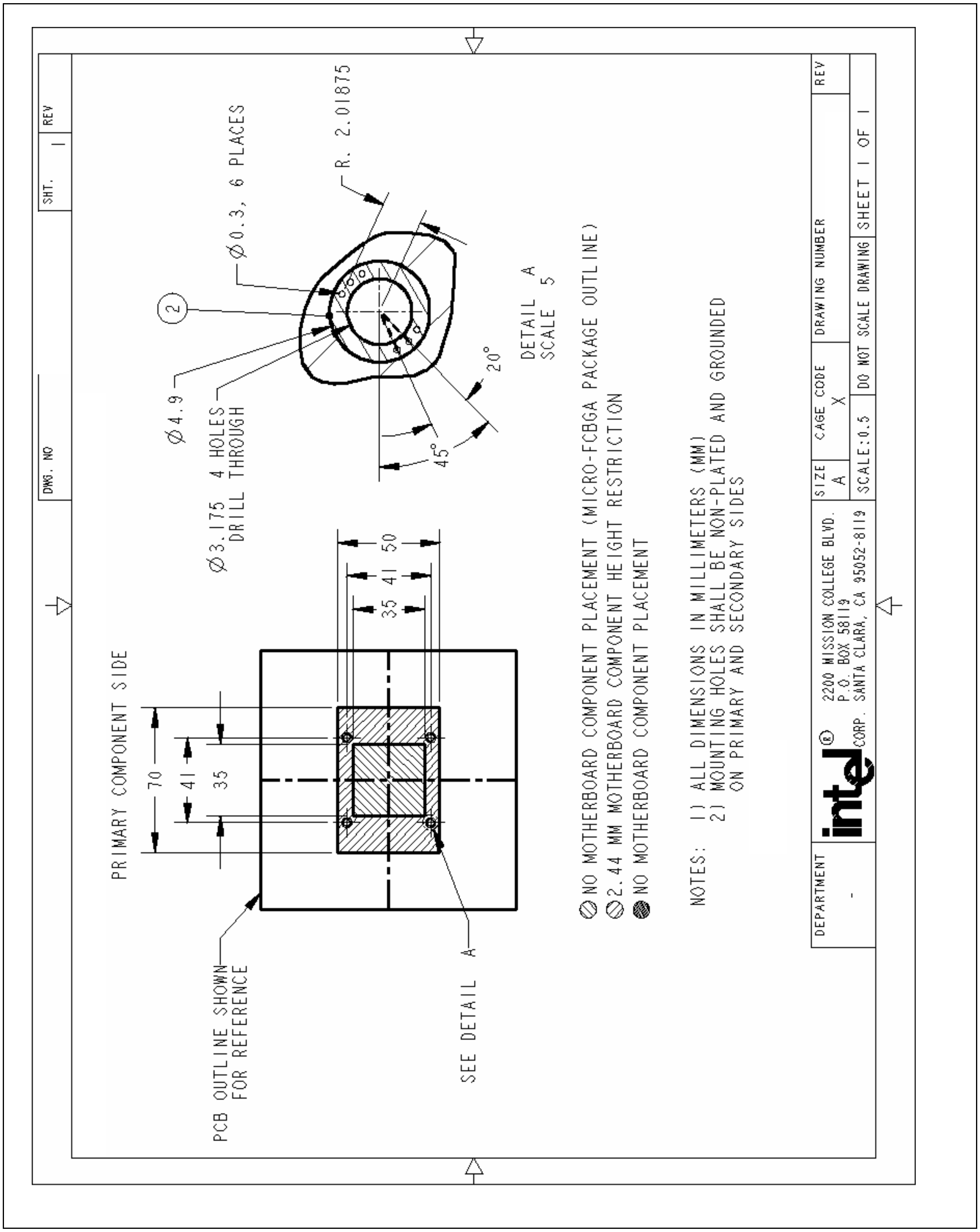


Figure 11. Natural Convection Heatsink Volumetric Constraint Zone (Secondary Side)

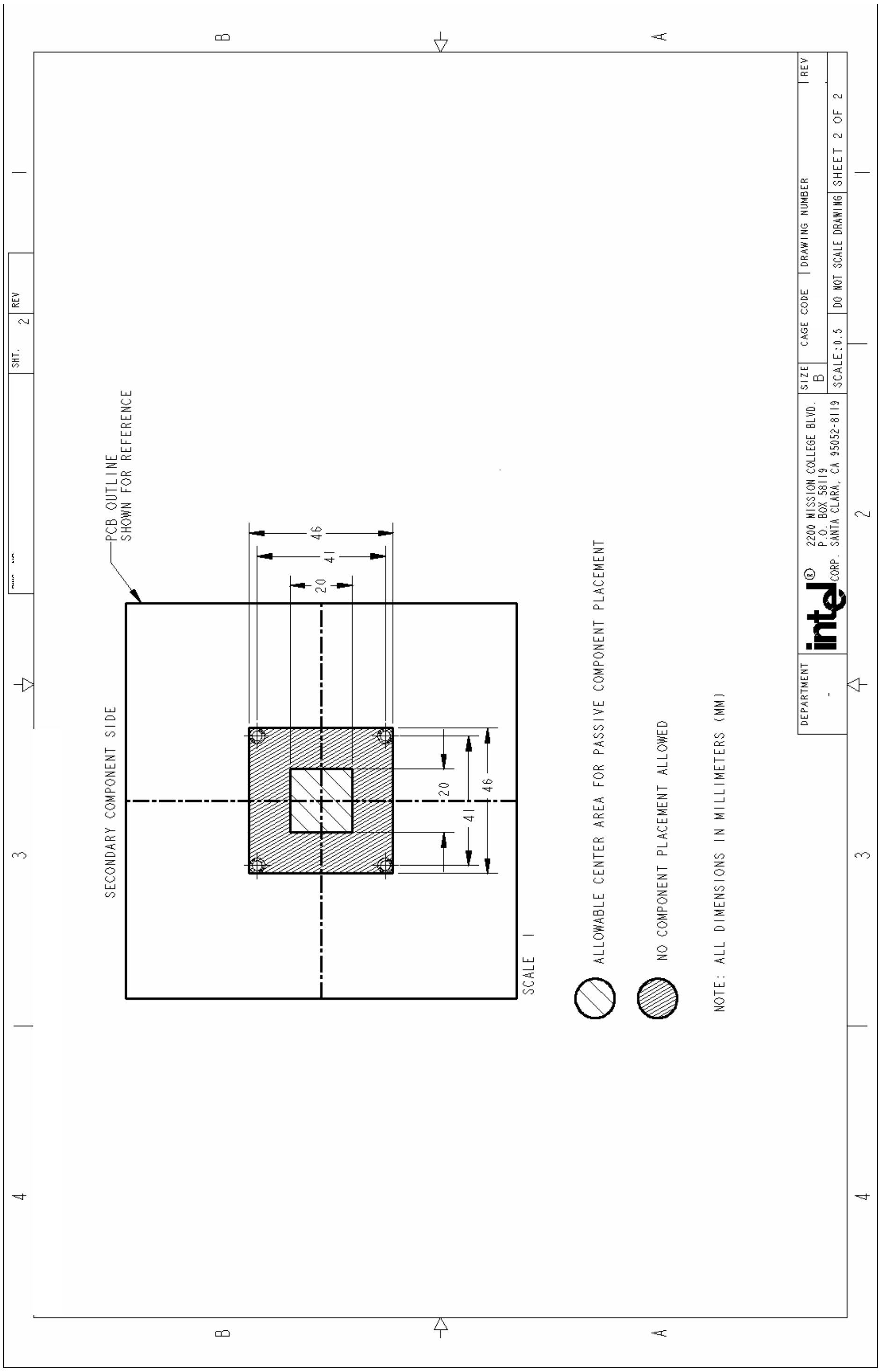


Figure 12. Mini-ITX Reference Thermal Solution (Extruded Aluminum)

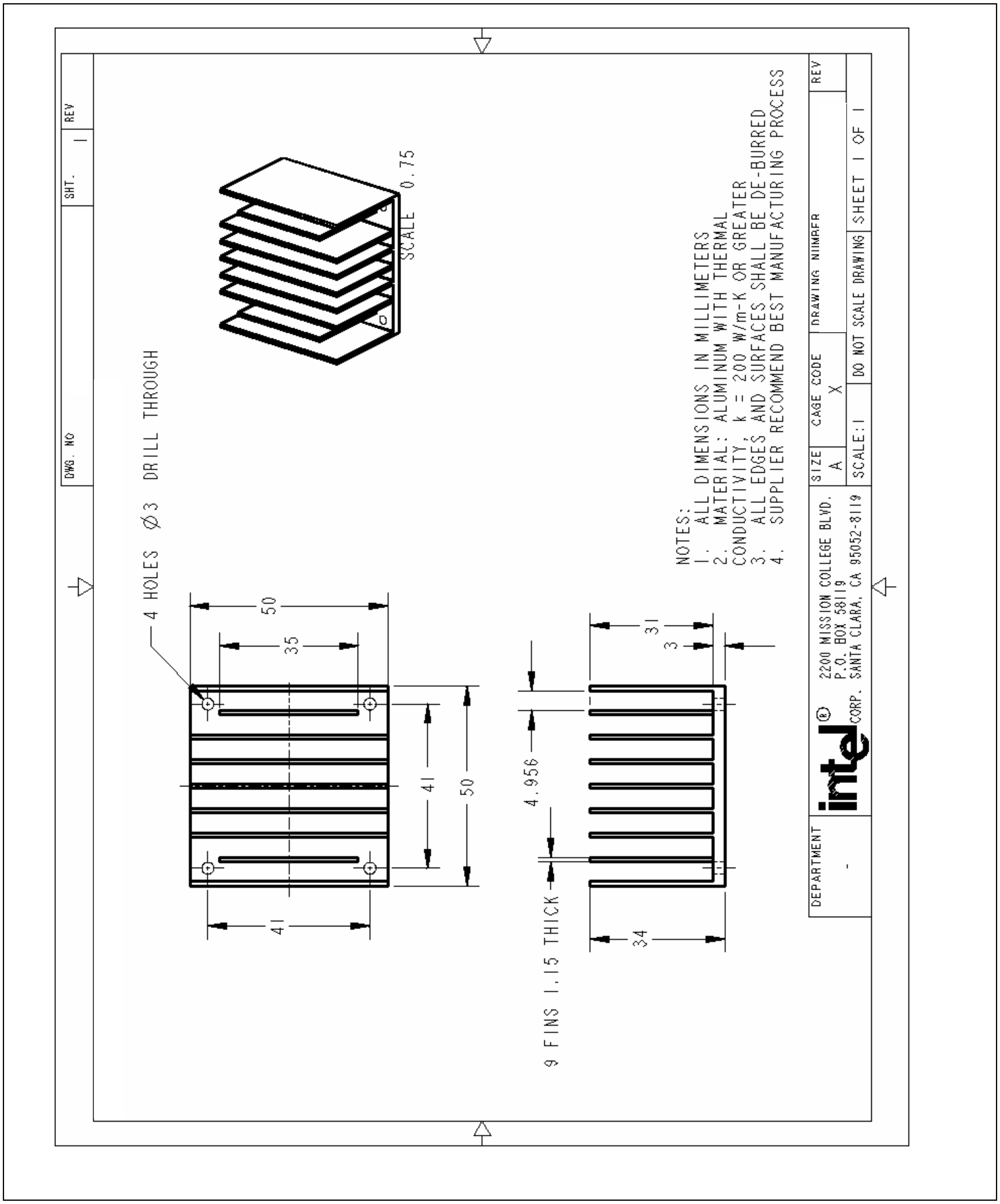


Figure 13. Vertical Compute Blade Thermal Solution